PHOSPHATE ROCK

(IN TWO PARTS)

1. MINING, BENEFICIATION, AND MARKETING

BY E. ROBERT RUHLMAN

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FOREWORD

The phosphate-rock industry in the United States has undergone tremendous development during the past 15 years as a result of expanded use of phosphate rock in fertilizers and a broad variety of chemicals. This report (which, it is believed, will have wide public interest), is in two parts. Part I deals with mining, beneficiation, and marketing. Part II will cover processing and utilization.

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1. Mining, Beneficiation, and Marketing

by

E. Robert Ruhlman[1/]

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SUMMARY AND INTRODUCTION

"Phosphate rock" is a broad term applied to natural deposits of minerals valued chiefly for their phosphorus content. More specifically, phosphate rock may be defined as a natural rock containing one or more phosphate minerals, usually calcium phosphate, of sufficient purity and in sufficient quantity to permit its use directly, or after beneficiation, in the manufacture of phosphorus-bearing products.

The grade or quality of phosphate rock is expressed either in terms of its phosphorus oxide (P_2O_5) content or the equivalent in tricalcium phosphate ($Ca_3(PO_4)_2$). The trade name for tricalcium phosphate is bone phosphate of lime (B. P. L.).

Phosphate rock ranges from massive, fine-grained material to friable material resembling weathered sandstone or soft clay. It has a specific gravity of 2 to 3 and ranges in color from almost pure white through various shades of brown and gray to almost jet black. It varies in grade from material containing 40 percent P_2O_5, or nearly pure tricalcium phosphate, to phosphatic limestones and shales containing less than 15 percent P_2O_5. The most common impurities are iron and aluminum compounds, silica, and calcium carbonate, but minor quantities and traces of many other elements often are present.

Most phosphate rock is used in manufacturing fertilizer materials essential for maintaining and expanding agricultural output. Large and increasing quantities are consumed in manufacturing chemical products of great importance to our national economy.

Since the domestic phosphate deposits minable under present conditions are adequate to supply our needs for many years, phosphate rock is not classed as a strategic material, yet of all the nonmetallic ores mined and processed in large tonnages, it ranks among the most indispensable.

Origin, Nature, and Composition

Phosphate-rock deposits are of widely different origin and vary greatly in structure, physical characteristics, and quality. In some types there is little evidence of organic origin; in others, fossil teeth, bones, and phosphatic shells abound.

Apatite, the purest phosphate mineral found in relatively large bodies, occurs in igneous crystalline rocks and is essentially calcium phosphate, containing variable minor quantities of chlorine, fluorine, or a hydroxyl radical. The most common variety is fluorapatite ($Ca_5(PO_4)_3F$), which contains approximately 40 percent P_2O_5 or the equivalent of 90 percent tricalcium phosphate (B. P. L.). Apatite is

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considered the original source of P_2O_5 in the soil, as well as of virtually all natural commercial phosphate deposits. Apatite is appreciably soluble in carbonated water and organic solutions. Some of the dissolved mineral is carried to the sea, where it is absorbed and concentrated by living organisms and reacts with other products of rock decomposition to form secondary phosphates.

Secondary phosphates are largely noncrystalline or amorphous sediments of marine origin and occur in many different types of deposits of various geologic ages. They are found in the Ordovician, Silurian, Devonian, Carboniferous, Jurassic, Cretaceous, and Tertiary ages and even in beds of more recent age. Some phosphate deposits, such as those in Tennessee, Arkansas, and the Western States, occur in well-defined strata, like seams of coal, underlain and overlain by limestone, chert or shale; other such as those in Florida and South Carolina, consist of unconsolidated mixtures of phosphate rock and various minerals.

The older deposits of secondary phosphates were laid down as sediments when the oceans invaded the land area in the United States, forming large inland seas. In certain areas these strata were subsequently folded, faulted, and actually overturned by geologic upheavals, causing the phosphate beds to dip at various angles and either brought closer to the surface or buried more deeply under other formations. In some instances the phosphate deposits have been enriched by weathering, leaching, and precipitation from phosphate-bearing solutions, while in others they have been diluted through erosion and mixing with other minerals.

The most recent secondary or amorphous phosphates were derived from guano, largely bird droppings that have accumulated over the years on certain islands in the Pacific and Indian Oceans, as well as in the Caribbean Sea. Where the guano has been protected from leaching, as in arid regions or in caves, the material contains both nitrogen and phosphate compounds in an available form and is a valuable fertilizer, requiring no chemical processing. In humid regions, however, the soluble phosphate content of guano has been dissolved and converted into relatively insoluble calcium phosphate by reaction with underlying coral or limestone strata. Where replacement of the CO_2 in the limestone by P_2O_5 has been virtually complete, the phosphates are high grade and can be used without further treatment.

Except for deposits derived from the leaching of guano, all natural phosphates contain 2 to 4 percent combined fluorine. Deposits derived from guano contain less than 1/2 percent fluorine.

Commercial Classes

During the past 30 years phosphate-rock deposits of progressively lower grade have been mined. The introduction of flotation, to separate finely divided phosphate particles (down to 200-mesh) from silica sand, permitted commercial utilization of deposits formerly considered noneconomic. Development of the electric furnace made possible the use of lower grade phosphate rock for manufacturing elemental phosphorus. These developments opened a large market for low-grade phosphatic material and greatly prolonged the life of certain phosphate fields.

The prime factors that determine whether or not a certain grade of phosphate can be economically exploited are the accessibility of the deposits, their distance from consuming centers, and the availability of fuel, chemical reagents, and electric power.

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Broadly speaking, commercial phosphate rock falls into the three following classes:

1. Acid-grade rock, containing more than 30 percent P_2O_5 (68 percent B. P. L.), which can be converted into marketable products by treatment with sulfuric, phosphoric, or nitric acid.

2. Furnace-grade rock, containing as little as 24 percent P_2O_5, (52 percent B. P. L.), which is suitable for manufacturing elemental phosphorus.

3. Finely ground phosphate rock (minus-200-mesh) which is applied directly to the soil. Such rock contains a minimum of 20 percent P_2O_5, with no restrictions on the impurities contained therein.

ACKNOWLEDGMENT

Special acknowledgment is due W. H. Waggaman,[2/] an authority on phosphate-rock processing, for valuable contributions to this report.

PRODUCTION AND RESERVES

Phosphate minerals are widely distributed in nature, but deposits of phosphate rock minable under present technologies are confined to limited areas in five continents and a number of islands in the Pacific and Indian Oceans and the Caribbean Sea.

World Production

The major areas, in order of decreasing production, are:

1. United States - Florida, Tennessee, Idaho, Montana, Wyoming, and Utah.

2. North Africa - French Morocco, Tunisia, Algeria, and Egypt.

3. Europe - U. S. S. R.

4. Oceania - Nauru, Ocean, Makatea, and Angaur Islands.

5. Asia - Christmas Island, Jordan, and Israel.

6. South America - Brazil and Chile.

The annual production of phosphate rock, by continents, for the period 1940-55, shown diagrammatically in figure 1, illustrates clearly the increasing demand for phosphatic fertilizers and chemicals.

Reserves

World resources of phosphate rock total many billion tons, but the bulk of the known deposits is of a marginal or submarginal nature that cannot be economically exploited under present technologies. Therefore, the broad term "reserves" has little meaning unless qualified.

2/ Formerly commodity-industry analyst, Bureau of Mines.

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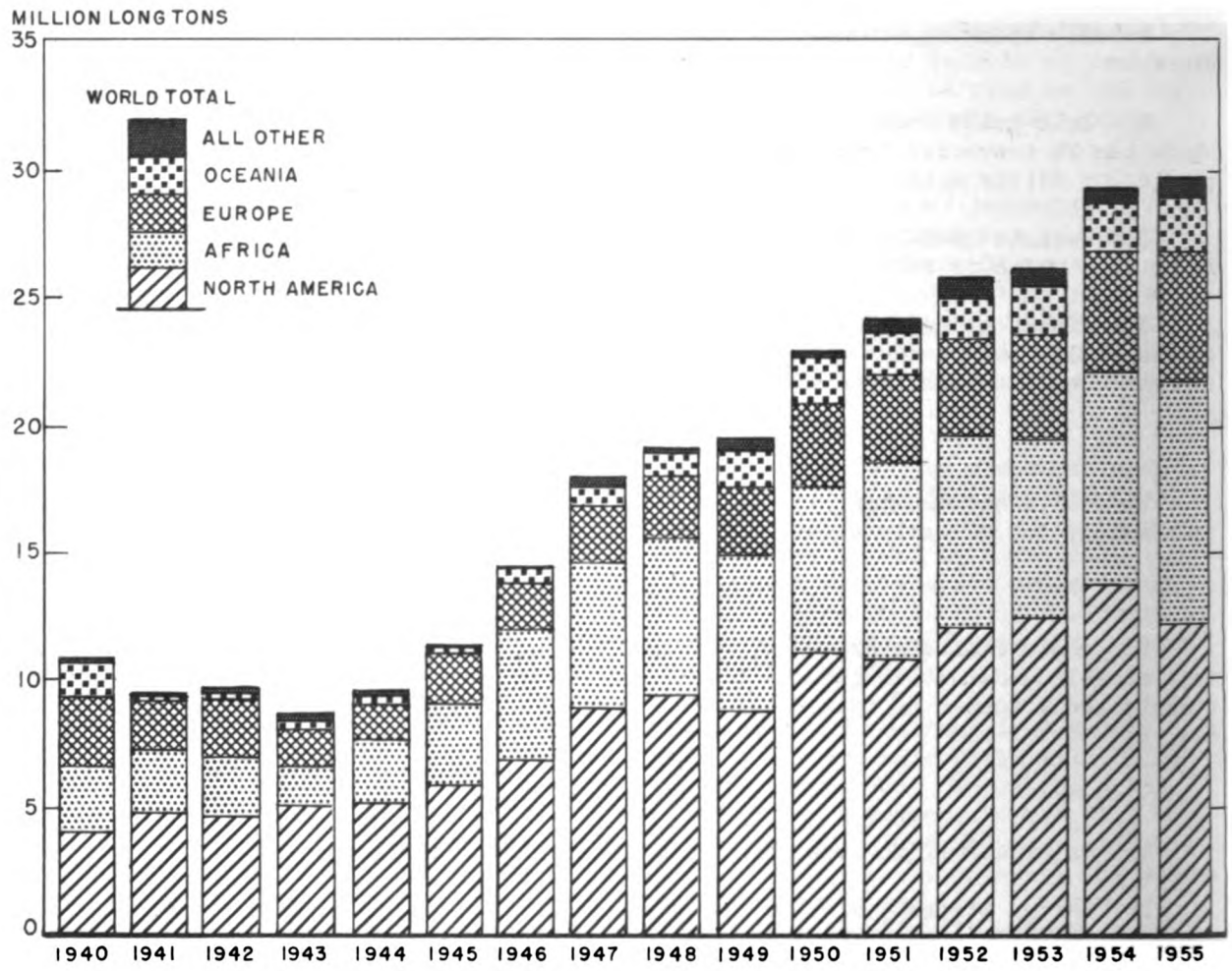

Figure 1. - World production of phosphate rock, 1940-55.

The total reserves of phosphate rock, by countries, as estimated by Jacob (13)3/ in 1953, are given in table 1. This estimate includes phosphates that can be beneficiated to 20 percent P_2O_5 (44 percent B. P. L.) or more, but what proportion of these deposits can be developed at present is problematical.

TABLE 1. - World reserves of phosphate rock and apatite

Country	Million long tons
French Morocco	21,000
United States	13,526
U. S. S. R.	7,568
Tunisia	2,000
Algeria	1,000
Brazil	572
Islands of Pacific and Indian Oceans	182
Egypt	179
23 other countries	670
Total	46,697

3/ Underlined numbers in parentheses refer to citations in the bibliography at the end of this report.

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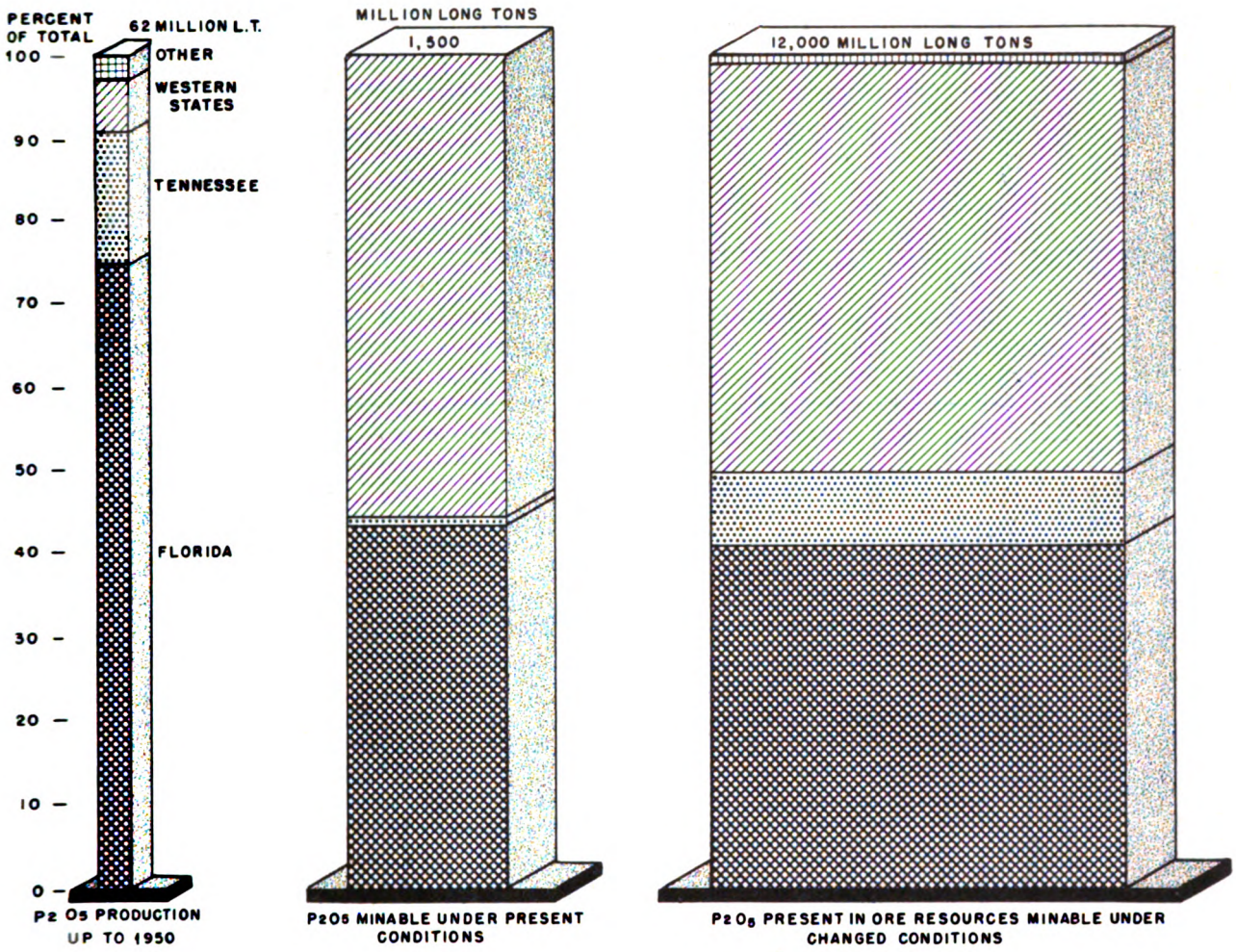

Figure 2. - Past production and estimated resources of phosphate rock in million long tons, in the United States.

The most recent estimates of United States reserves of phosphate rock (in terms of P_2O_5) are those of the Federal Geological Survey, which are given in table 2 and shown diagrammatically in figure 2 (41). In these latter estimates the domestic reserves are placed in two categories: (a) Minable under present conditions; (b) minable under changed conditions. Approximately 90 percent fall into the second category.

It will be noted, however, that the P_2O_5 in the rock produced in the past 84 years or more was only about 4 percent of that in the remaining reserves of minable rock. Therefore, at the present rate of production the minable reserves are sufficient for fully 500 years.

DOMESTIC PHOSPHATE-ROCK DEPOSITS

The occurrence of phosphate rock has been reported in 23 States in the United States. Some of these deposits are relatively unimportant and some have been mined to a very limited extent. Presently producing mines are in Florida, Tennessee, Idaho, Utah, Montana, and Wyoming.

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TABLE 2. - Production and resources of phosphate rock in the United States

Source and type	Production, million long tons		Inferred reserves minable under present conditions, million long tons		Additional inferred resources minable under changed conditions, million long tons	
	Marketed product	Approximate P_2O_5 content	Marketable product	P_2O_5 content	Product	P_2O_5 content
Florida:						
Land pebble:						
In matrix	1/124.7	41.7	2/1,000	2/330	2/2,000	2/600
In leached zone	-	-	-	-	2/800	180
River pebble	3/1.3	.3	-	-	50	12
Hard rock	4/14.0	4.8	4/1,040	330	4/500	140
Soft rock	1.1	.2	(5/)	(5/)	(5/)	(5/)
Hawthorn formation	-	-	-	-	20,000	4,000
Total Florida	141.1	47.0	2,040	660	23,350	4,932
South Carolina:						
Land rock	6/9.3	2.5	-	-	9	2.4
River rock	6/4.1	1.0	-	-	(9/)	(9/)
Total South Carolina	13.4	3.5	-	-	9	2.4
Tennessee:						
Brown rock	7/31.1	9.0	85	15	(9/)	(9/)
Blue rock	7/1.3	.4	-	-	83	25
White rock	.02	.007	-	-	15	4
Phosphatic limestone	-	-	-	-	5,300	1,100
Total Tennessee	8/33.3	8/10.0	85	15	5,398	1,129
Western field (Phosphoria formation)	6.8	1.9	2/3,000	870	2/20,000	5,800
Arkansas	.03	.01	-	-	20	5
Other States (Alabama, Kentucky, North Carolina, Pennsylvania)	.17	.05	-	-	(6/)	(6/)
Grand total (rounded)	195,00	62,00	5,100	1,500	49,000	12,000

1/ Includes some river pebble and soft rock. 2/ Based on Federal Geological Survey investigations. 3/ Some river pebble included with land pebble. 4/ Includes soft rock. 5/ Included with hard rock. 6/ Some river rock included with land rock. 7/ Virginia apatite and some blue rock included with Tennessee brown rock. 8/ Figure is higher than sum of individual items because separate data for different types of Tennessee phosphate are not available for years before 1905. 9/ Not available.

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Florida

Three types of phosphate rock are being mined and marketed in Florida; namely, hard-rock phosphate, pebble phosphate, and soft rock or colloidal phosphate.

Hard-Rock Phosphate

The hard-rock phosphate region lies toward the west side of the Florida Peninsula, extending in a general north and south direction from Suwanee and Columbia Counties to Citrus and Hernando Counties, a distance of over 100 miles.

The rock occurs as nodules and boulders embedded in a matrix of sand, clay, limestone, and soft phosphate, which must be separated from the phosphate rock by washing, screening, or hand picking. Individual beds range in area from less than 100 square feet to several acres and from a few feet up to 100 feet in thickness. They are covered by an overburden of sand and clay ranging from less than 1 foot to more than 50 feet in depth.

Hard-rock phosphate varies considerably in physical characteristics but usually consists of hard, dense white or cream-colored rock ranging in size from boulders weighing several tons to small nodules and fine sandlike particles. When washed and screened, Florida hard rock is the highest grade phosphate produced in the United States, averaging 35 percent P_2O_5 (76.5 percent B. P. L.), with a combined iron oxide and alumina content of less than 3 percent.

At one time 75 companies were active in the Florida hard-rock fields, and much of the rock was exported. With development of the more extensive, low-cost Florida pebble-phosphate deposits, the production of hard rock decreased substantially, and only one firm was mining this type of phosphate in 1956. The entire output was used to produce elemental phosphorus.

The area is served by two railroads, improved highways, and port facilities on both the east and west coasts.

Pebble Phosphate

The Florida pebble district lies south of the hard-rock region and comprises parts of Polk, Hillsborough, Manatee, and Hardee Counties, an area of over 1,000 square miles. The higher grade and more extensively developed deposits are in Polk and Hillsborough Counties.

The land surface of this region is pine upland, with an elevation of 100 to 150 feet above sea level; the phosphate deposits are fairly continuous over wide areas. The deposits are flat, unconsolidated beds, average 30 feet in thickness, and consist of a matrix of coarse and fine phosphate pebbles mixed with sand, clay, and soft phosphate minerals of micron and submicron size. Ore tenor is not uniform but averages 15 percent P_2O_5. The beds are covered with an overburden of sand and clay ranging from 5 to 50 feet in thickness, averaging 15 feet. The grade of the rock after beneficiation is 30 to 36 percent P_2O_5 (65 to 78 percent B. P. L.) and averages 33 percent P_2O_5, with a combined ferric oxide and alumina oxide content of less than 3 percent. The distribution of the B. P. L. or its P_2O_5 equivalent in the matrix, as determined in an investigation conducted by S. P. Warren in 1948, is given in table 3 (38). Only 61 percent of the B. P. L. in the matrix is being recovered in the form of marketable products (fig. 3).

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TABLE 3. - Distribution of B. P. L. in Florida pebble-phosphate matrix and proportions present in recovered and rejected products

B. P. L. in matrix[1/] recovered products, and waste, percent	Gross weight, tons	B. P. L. content	
		Tons	Percent of total
Phosphate matrix (36% B. P. L.)	100.00	36.0	100.0
Coarse pebble (72.0% B. P. L.)	1.85	1.3	3.7
Medium pebble (72.0% B. P. L.)	3.30	2.4	6.6
Fine pebble (72.2% B. P. L.)	3.60	2.6	7.2
Total pebble (72.2% B. P. L.)	8.75	6.3	17.5
Coarse flotation (75.0% B. P. L.)	5.90	4.4	12.2
Fine flotation (76.0% B. P. L.)	15.00	11.4	31.7
Total flotation (75.8% B. P. L.)	20.90	15.8	43.9
Waste tailings[2/] (9.0% B. P. L.)	36.65	3.2	9.0
Slimes (+200 mesh) (27.4% B. P. L.)	11.00	3.0	8.4
Slimes (-200 mesh) (34.8% B. P. L.)	22.70	7.9	21.9
Total slimes (32.4% B. P. L.)	33.70	10.9	30.3
Grand total	100.00	36.2	100.7

1/ Bone phosphate of lime or tricalcium phosphate, $Ca_3(PO_4)_2$.
2/ Tailings from flotation treatment.

Approximately one-third of the 1,800 square miles of prospected Florida pebble-phosphate deposits is overlain by a so-called "leached zone" averaging from 6 to 7 feet in thickness (1). This leached-zone material, which represents the gradational contact between the barren overburden and the phosphate matrix currently mined, consists of a friable phosphatic sandstone composed of quartz and phosphatic clay. Its alumina content ranges from 6 to 15 percent and its P_2O_5 content from 12 to 20 percent. The bulk of the P_2O_5 present, however, is in the form of finely divided (minus-150-mesh) wavelite and pseudo wavelite (hydrated compounds of aluminum and calcium-aluminum phosphate) and hence can be largely separated from the coarser quartz grains by crushing the loosely cemented rock and treating the disintegrated material by screening and wet-classification processes. Under current mining practice the leached zone material is removed and rejected, along with the overburden.

Eight companies were actively engaged in producing Florida pebble phosphate in 1956. They not only market the washed and dried pebble but also manufacture fertilizers and various phosphate chemicals.

Excellent highways and two railroads serve this area. Ample port facilities are available on the west coast.

Soft Phosphate

Soft phosphate is a gray or tan colloidal phosphatic clay containing variable quantities of P_2O_5. This material usually is associated with the hard rock and pebble deposits. During 1956 in the hard-rock region, pockets of soft phosphate were mined, dried, ground, and sold by six companies for direct application to the soil under the name of colloidal phosphate.

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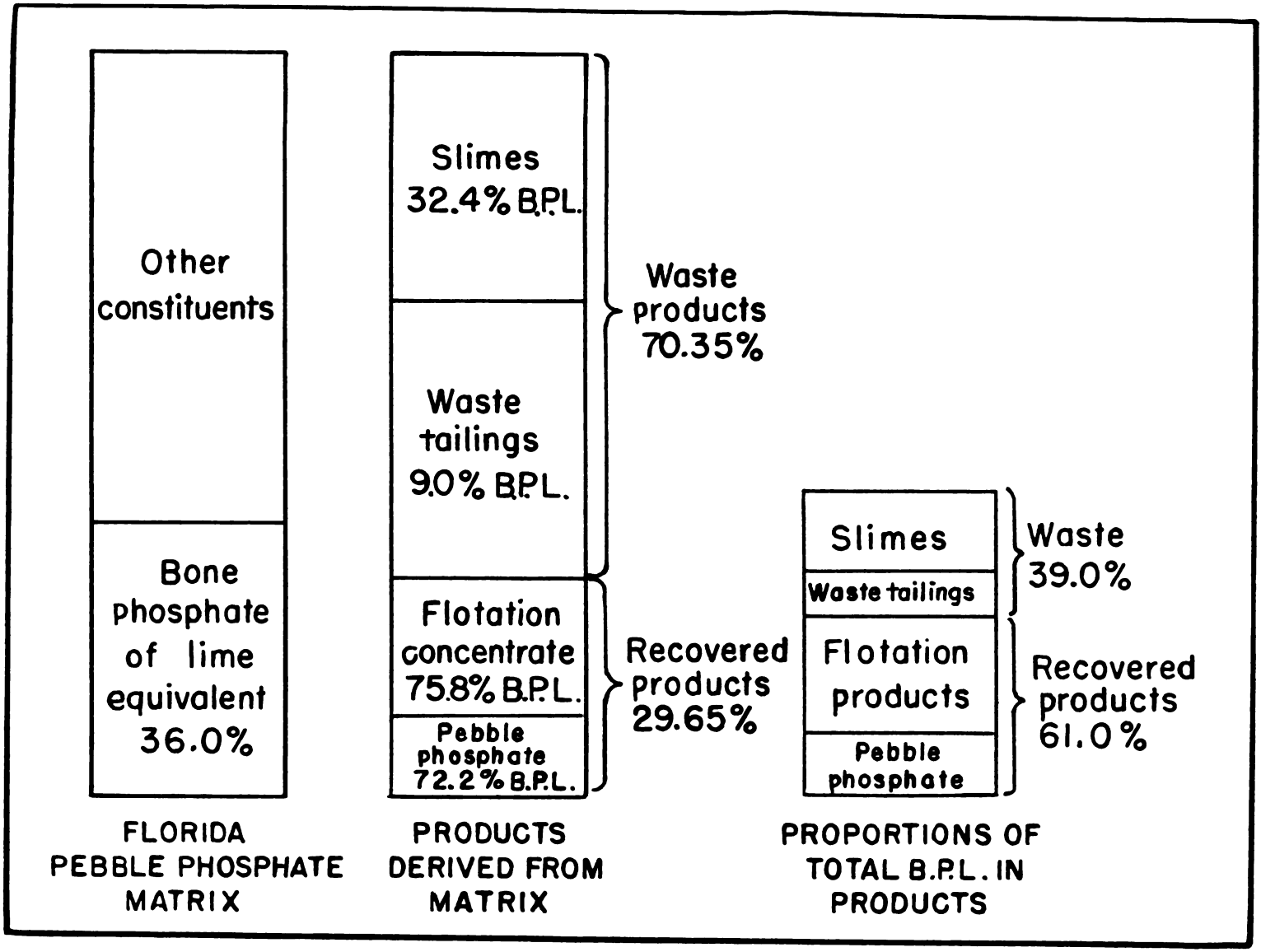

Figure 3. - Distribution of products derived from land-pebble phosphate rock, percent.
(Source: National Academy of Sciences Report MMAB-45-C.)

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Tennessee

There are three types of phosphate rock in Tennessee, called brown, blue, and white rock. Only the brown rock was being produced in appreciable quantities in 1956.

Brown Rock

The brown-rock area comprises a belt 130 miles long and 30 miles broad at its widest point, extending in a general north and south direction from the Kentucky to the Alabama borders. Not all of this phosphate belt contains minable deposits, and most of the known deposits of acid-grade phosphate rock are exhausted. The deposits of commercial importance occur chiefly in Hickman County.

The deposits are of marine origin and are residual material from the weathering of phosphatic limestone. The rock varies in color from light gray to deep chocolate brown and in texture from relatively close grained plates to coarse, disintegrated material intermingled with siliceous impurities. The grade of the ore ranges from 20 to 25 percent P_2O_5.

The brown-rock-phosphate area is well provided with transportation facilities, but much of the material is used close to the mines to produce elemental phosphorus. The phosphorus is shipped to plants within and outside the State for conversion into phosphoric acid and other phosphate chemicals.

Blue Rock

The blue-rock-phosphate area is more restricted than the brown rock. Deposits occur in parts of Hickman, Lewis, and Perry Counties.

The blue-rock phosphate occurs in strata ranging from a few inches to 4 feet in thickness. It varies considerably in grade, ranging from a phosphatic shale of little or no commercial value to a dense, highly phosphatic rock. The better grades, often oolitic in appearance, have a content of 28 to 34.5 percent P_2O_5 (61 to 75 percent B. P. L.) but average about 30 percent P_2O_5 (65.5 percent B. P. L.).

Very little blue phosphate is being produced at present. The expense of mining and preparing it for the market makes it difficult to compete with Tennessee brown rock, which occurs in thicker, more accessible deposits. It was reported that the blue-rock deposits constitute the bulk of the remaining phosphate reserves in Tennessee and, with improvements in mining and beneficiation methods, may be more important in future (3).

White Rock

White phosphate rock resembles the hard-rock phosphate of Florida and occurs in pockety deposits in Perry and Decatur Counties as three types - stony, breccia, and lamellar. The last is the most important, since it is more plentiful and has been enriched by precipitation from phosphate solutions. Limited quantities containing as high as 39 percent P_2O_5 (85 percent B. P. L.) have been found, and carlots containing 32 to 35.5 percent P_2O_5 (70 to 76.6 percent B. P. L.) have been shipped. The deposits, however, are very irregular in occurrence, and there are wide fluctuations in grade. Moreover, the average cost of mining is considerably higher than for brown rock. Little white rock is being produced at present.

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Phosphates of the Western States

The western phosphate field occurs in parts of Idaho, Montana, Utah, Wyoming, and Nevada.

The rock is of marine origin and was originally deposited in relatively flat beds, which later were intensely folded, faulted, and eroded. The phosphate-bearing formations are exposed in narrow bands along the flanks of the larger, simpler folds, in more complex crumplings in the smaller folds, and along the borders of the faulted areas. The beds dip at various angles from nearly horizontal to vertical.

The currently economic phosphate-bearing strata range from 75 to 180 feet in thickness and consist of strata of phosphatic sandstones, dark-brown to black limestones, and 1 to 3 relatively high grade beds of gray, brown, or black oolitic phosphate rock. In some localities the total thickness of the better grade phosphate strata ranges from 10 to 30 feet, but the individual beds average from 3 to 7 feet in thickness and vary in grade from 26 to 36 percent P_2O_5 (57 to 78.8 percent B. P. L.). Unlike the Florida phosphates and many of the remaining brown-rock deposits of Tennessee, the higher grade phosphates of the Western States require little or no washing or other forms of beneficiation.

In addition to the acid-grade rock, the western phosphate formations contain large quantities of phosphatic shales interbedded with phosphate rock and limestone. These shales vary widely in P_2O_5 content. Some are suitable, either directly or when blended with higher grade rock, for producing elemental phosphorus, but substantial tonnages are not mined. Utilization of these shales may follow development of new or improved mining and beneficiation techniques.

Eight companies were mining western phosphate rock in 1956, and most of them were manufacturing finished or semifinished products at or near the source of raw materials at the end of the year.

South Carolina

The phosphate area of South Carolina is confined to a coastal belt about 20 miles wide extending from the Wando River in Charleston County to the Broad River in Beaufort County. This region is near tide level and is intersected by numerous creeks and estuaries. The South Carolina phosphate rock occurs in land and river deposits. These two types of deposits are composed of the same material, river rock being merely the land rock washed down and concentrated in the beds of streams.

The phosphate beds, which usually are overlain by a relatively thin overburden of sand and clay, have a maximum thickness of 30 inches and average 12 inches. The phosphate rock occurs as nodules of various sizes, often pitted and filled with clay and sand, which must be removed to obtain a marketable product. After washing and drying, the South Carolina phosphate rock averages 28 percent P_2O_5 (60 percent B. P. L.) with low iron oxide and alumina but high calcium carbonate content.

The South Carolina phosphate deposits were mined during the period 1868-1912, and production reached a peak of 618,600 tons in 1893. Subsequently the output declined because of development of the higher grade and lower cost Florida pebble deposits.

Although no phosphate rock has been marketed from South Carolina since 1921, these deposits are not exhausted. A 1942 estimate placed the reserves at 8,900,000 tons, exclusive of river rock (17).

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Kentucky

Phosphate rock has been reported in parts of Fayette, Jessamine, Scott, and Woodford Counties. The phosphate rock is similar to that occurring in the Tennessee brown-rock field and consists of loosely coherent plates of varying thickness separated from each other by a porous mixture of finely divided phosphate granules and clay. Although individual samples of Kentucky phosphate contain as high as 35.5 percent P_2O_5 (78 percent B. P. L.), the average grade is probably less than 32 percent P_2O_5. The workable beds have proved spotty and do not compare favorably in thickness and extent with those of Tennessee.

From 1912-26, about 93,000 long tons of Kentucky rock was mined, chiefly in the vicinity of Wallace, Woodford County. No marketed production has been reported since 1926. The reserves of Kentucky phosphate are estimated to be 770,000 tons.

Arkansas

Occurrences of phosphate-bearing rock have been reported from a number of localities in Arkansas, but deposits have been developed only in the northwestern part of Independence County along Lafferty Creek, north and west of the White River, about 10 miles from Batesville.

The phosphate deposits in the developed area occur in two strata, one directly overlying the other. The upper stratum is 3-1/2 to 4 feet thick and is a hard gray or brown rock made up of closely cemented fragments of phosphatic material. This bed contains 25 to 27.5 percent P_2O_5 (55 to 60 percent B. P. L.). Directly under this bed, although sometimes separated by a thin layer of manganiferous iron oxide, is a second bed of lower grade phosphatic material approximately 4 feet thick, containing 14 to 18.5 percent P_2O_5 (30 to 40 percent B. P. L.).

From 1902 to 1912, 31,500 tons was mined from the upper phosphate bed and shipped to Little Rock, where it was manufactured into low-grade superphosphate. Competition from higher grade brown phosphate rock in Tennessee forced this mine to close in 1912. No production has been reported since.

A phosphate deposit in this area was churn-drilled by the Federal Bureau of Mines in 1949. Although this bed was 16 feet thick, it occupied a relatively small area and contained only 18.8 percent P_2O_5 (41 percent B. P. L.). Beneficiation tests, however, showed that the rock could be upgraded to 32.9 percent P_2O_5, with a recovery of 70 percent of its phosphate content.

The Arkansas phosphate reserves were estimated at 90 million long tons.

Virginia

In Nelson and Amherst Counties large, dikelike bodies of ore occur, consisting of a mixture of apatite and ilmenite and apatite and rutile (titanium dioxide). This ore is known as nelsonite because it was first found in Nelson County.

Ilmenite is the predominant mineral in nelsonite and constitutes approximately 45 percent of the weight of the ore. The apatite content averages about 20 percent. In its unweathered state nelsonite is a dark, hard, granular rock, but in certain areas it has been weathered to depths of 70 to 90 feet. The weathered material can be mined by power shovels or draglines.

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For many years little importance was attached to these deposits, except as a limited source of rutile, but when processes for manufacturing titanium pigments from ilmenite were developed, the nelsonite deposits began to attract considerable attention, and methods were devised for separating the constituent minerals. Exploitation of the weathered portions of these deposits was begun in 1937, and for a number of years ilmenite and high-quality apatite were mined and marketed. Ilmenite is still being mined and processed, but no apatite has been marketed from this area since 1948. The separated apatite is being stockpiled for future use.

MINING METHODS

Because of the wide difference in the mode of occurrence, physical nature, and composition of phosphate-rock deposits, mining methods are adapted to each particular type of deposit.

Underground Mining

Underground mining of the western phosphate-rock deposits has been practiced to a limited extent since 1906, but in recent years operations have been greatly expanded. Nearly 40 percent of the phosphate rock produced in the Western States is now mined underground.

The mines originally were developed by adits; but as the ore above adit level was mined out, shafts were sunk to develop additional ore. When the hanging wall of the deposits consists of massive chert or limestone, comparatively little timbering is required, and a room-and-pillar mining method is used. The area to be mined is developed from the haulage level, and the stopes are advanced by breast stoping up the dip. The width of the stopes and pillars is governed by ground conditions, which change considerably, even in the same mine.

Other underground-mining methods that have been utilized to a limited extent but are not being used now include shrinkage, top slice, cut-and-fill, and longwall stoping. Most underground operations are limited to acid-grade phosphate beds. One company, however, is mining a lower grade deposit to obtain ore for manufacturing elemental phosphorus.

The Bureau of Mines initiated a research program during 1954 on mining methods designed to extract phosphate rock from underground bedded deposits at reduced cost by development and utilization of mechanized equipment. The first model of a phosphate-rock planer (fig. 4) developed by the Bureau of Mines was operated experimentally in the Anderson mine of the Montana Phosphate Products Co., at Garrison, Mont. (12). Results of this preliminary testwork were encouraging, and a new planer was being constructed at the end of 1956.

Open-Pit Mining

Open-pit mining is practiced where the overburden is relatively thin or of such a nature that it can be readily removed by scrapers, draglines, or hydraulic means.

Western Phosphates

In certain parts of the western phosphate fields the upper shales have been eroded, leaving an overburden ranging from 15 to 30 feet in thickness. This overburden is stripped by tractor-drawn scrapers. A layer of limestone, 22 inches to 24 inches thick, directly overlying the phosphate beds, is removed by power shovels, which also are used to mine the phosphate strata. Very little blasting is required.

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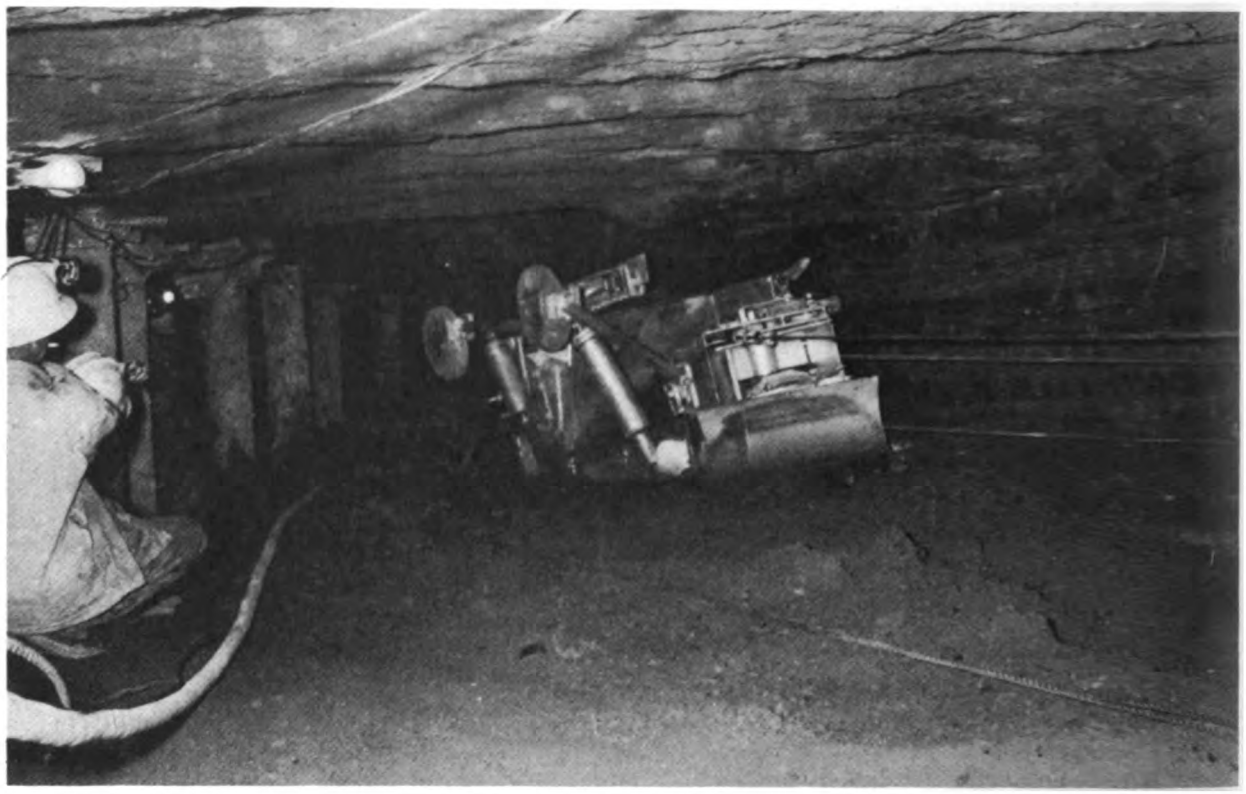

Figure 4. - Experimental planer developed by Federal Bureau of Mines for underground mining of deposits in the western phosphate field.

On the Fort Hall Indian Reservation, 16 miles east of Fort Hall, Idaho, the Phosphoria formation outcrops for several miles. In this locality the main high-grade bed of 32 to 34 percent P_2O_5, 6 feet thick, is overlain by a 21-foot-thick bed of lower grade phosphate rock averaging 24 percent P_2O_5, which is mined for elemental phosphorus manufacture. An overlying 18-foot-thick bed of phosphatic shale is stockpiled for possible future use. Overburden ranges from a few feet up to 100. Tractors, power shovels, and dump trucks strip the overburden and mine the phosphate beds.

Tennessee Brown Rock

All brown-rock phosphate now produced in Tennessee occurs in more or less disintegrated form and is mined from open pits. The overburden, which ranges from a few feet to more than 50 feet in thickness, is stripped by draglines, and the underlying phosphate beds are mined with the same draglines. It is common practice to remove the overburden well in advance of actual mining operations. The crude ore or matrix is loaded into trucks or railroad cars and hauled to washer plants, where the phosphate is separated from the clay and silica gangue.

Florida Hard Rock

Florida hard-rock phosphate is mined exclusively by the open-pit method. The overburden, consisting mainly of sand and clay, is removed by hydraulic means. The ratio of overburden to ore largely determines the commercial importance of a deposit, and an economic ratio is 6 to 10 cubic yards of overburden per long ton of recoverable rock.

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Draglines are used to mine deposits as much as 45 feet below water level at the rate of 150 to 200 cubic yards of ore per hour. The larger boulders are blasted, and the ore is loaded into skips and hauled to the washer plant for beneficiation.

Because of the erratic nature of the hard-rock ore (matrix), some selective mining is required. Limestone cones or so-called "horses" frequently occur in these deposits and must be bypassed or discarded during mining.

Land-Pebble Phosphate

The Florida land-pebble deposits, from which 70 percent or more of the domestic phosphate rock is obtained, are also mined entirely by the open-pit method.

The overburden, consisting chiefly of loose sand ranging up to 50 feet in thickness but averaging 10 to 15 feet, is stripped by large draglines equipped with buckets ranging in size from 10 to 30 cubic yards and booms 100 to 275 feet in length. The overburden is deposited in the pits of adjacent mined-out areas.

The phosphate-rock beds, consisting of a matrix of sand, clay, and phosphatic material ranging in size from 1 inch or more down to less than 1 micron, are mined by the same draglines, deposited in piles that are washed into a sump with heavy streams of water, and pumped to the washer and flotation plants for beneficiation. A view of an open-pit mine in Florida is shown in figure 5.

BENEFICIATION OF PHOSPHATE ROCK

Nearly all of the phosphate rock produced in Florida and Tennessee is subjected to some ore-dressing processes before it is manufactured into finished products. Only a minor portion of the phosphate rock mined in the Western States is upgraded by washing and screening before being used for manufacturing elemental phosphorus or phosphatic fertilizers. However, some of the western rock used in manufacturing phosphoric acid by the "wet process" is calcined to burn out the organic matter, raise the grade, and simplify subsequent processing steps.

Except for soft phosphate, all crude ore mined in the hard-rock and pebble fields of Florida is washed and screened before it is marketed. A large proportion of the finer material, formerly discarded, is treated by flotation to recover the phosphate from the silica sand with which it is intimately associated. Development of washing and flotation techniques for upgrading Florida and Tennessee phosphates has increased the yield of marketable rock from the matrix (crude ore) and rendered feasible exploitation of deposits formerly considered to have little or no commercial value.

Phosphate Washer Plants

Modern phosphate washer plants are of all-steel construction and so designed that they can be dismantled and reerected at a new location when desired. However, if the new mine is within a maximum distance of about 5 miles of the washer, it is usually cheaper to extend the pipeline and pump the matrix up to about 5 miles rather than to dismantle and rebuild the washer plant.

Phosphate washers differ somewhat in detail. All are equipped with revolving trommels, crushers, screens of various size, and one or more sets of log washers. Hydroseparators are employed for removing slime, and several types of classifiers separate the finer sizes of washed and screened material before sending it to the

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Figure 5. - Open-pit mining operations in Florida pebble fields.
(Courtesy, International Minerals & Chemical Corp.)

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flotation plant. The hydroseparators are being replaced by cyclones, which perform more efficiently and require a lower capital investment. The following description is typical of the washing methods employed in the Florida pebble field:

The slurry of phosphate matrix and water (35 to 45 percent solids) is pumped to the head of the washer plant and discharged into a launder or tub fitted with a 1-mm. slotted screen. The bulk of the slime, as well as a substantial quantity of fine, granular material, passes through this screen into one or more hydroseparators for further treatment. The pulp retained by the 1-mm. screen is discharged into a trommel with 2-inch openings, where mud balls and small quantities of lime rock are removed. The mud balls are crushed in a hammer mill, and the disintegrated material is recycled. The pulp passing through the 2-inch openings of the trommel is washed over flat screens and then over double-deck vibrating screens to effect several separations of the material coarser than 1-mm. The larger pebbles (plus-3/8-inch) pass through one or more sets of log washers; and the backwash, consisting of slime and fine grains of phosphate and silica sand, discharges into a hydroseparator for further treatment and recovery of phosphate granules coarser than 200-mesh. The minus-3/8-inch material is subjected to further washing and screening and treated in a separate log washer.

Washers usually deliver pebble phosphate of the following sizes to the shipping bins:

1. Material ranging from minus-3/4- to plus-3/8-inch.

2. Material ranging from minus-3/8-inch to plus-1-mm.

Ordinarily the finer sizes are higher grade.

The bulk of the rejects from most washer plants is finer than 1 mm. These rejects, after being deslimed, are treated in various types of mechanical classifiers and constitute the feed for agglomeration tables and flotation cells. A typical flowsheet of a modern phosphate washer in the Florida pebble fields is shown in figure 6.

The washer plants for beneficiating Florida hard rock and Tennessee brown rock differ from those used in the Florida pebble fields, in that they are designed to recover finer sizes of phosphate without flotation. A typical flowsheet of a phosphate washer in Tennessee is shown in figure 7.

Agglomerate Tabling and Flotation

The minus-1-mm. material discharged from the Florida-pebble washer plant is a water suspension of finely divided phosphatic material, silica sand, and slimes of micron and submicron sizes. Before the phosphate can be recovered from this material, the slimes must be removed. Desliming is largely effected in hydroseparators and/or centrifugal cone classifiers. Whichever system is employed, the settled material still contains substantial quantities of slime and requires a number of repulping and settling steps, with additional quantities of fresh water to obtain a clean product.

The slimes discharged from the washer plants in the Florida pebble field contain approximately one-third of the P_2O_5 present in the original phosphate ore and in the Tennessee brown-rock field contain nearly one-half of the P_2O_5 present in the original phosphate ore. These slimes represent large losses of potential phosphate

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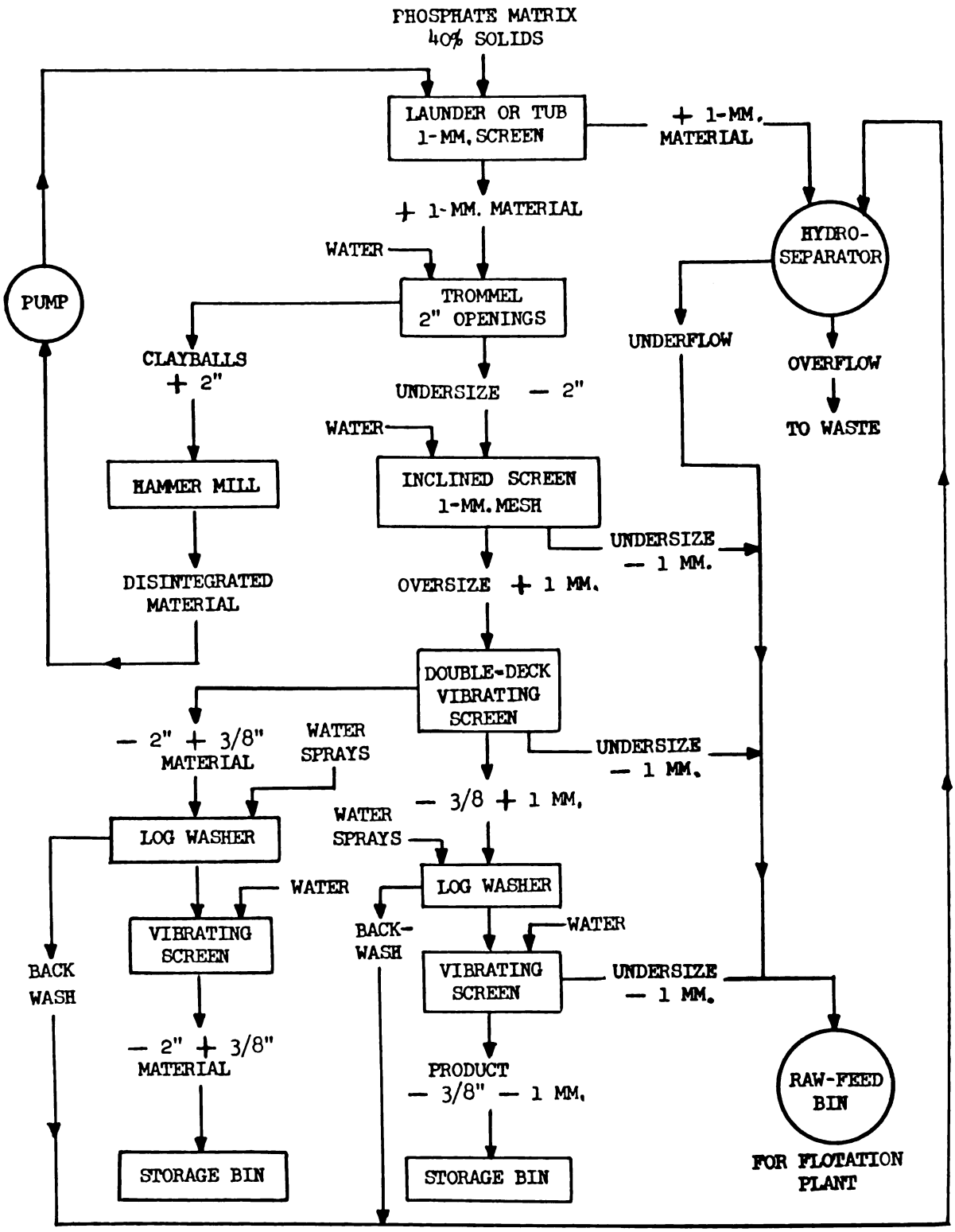

Figure 6. - Simplified flowsheet of washer plant for recovering Florida pebble phosphate.

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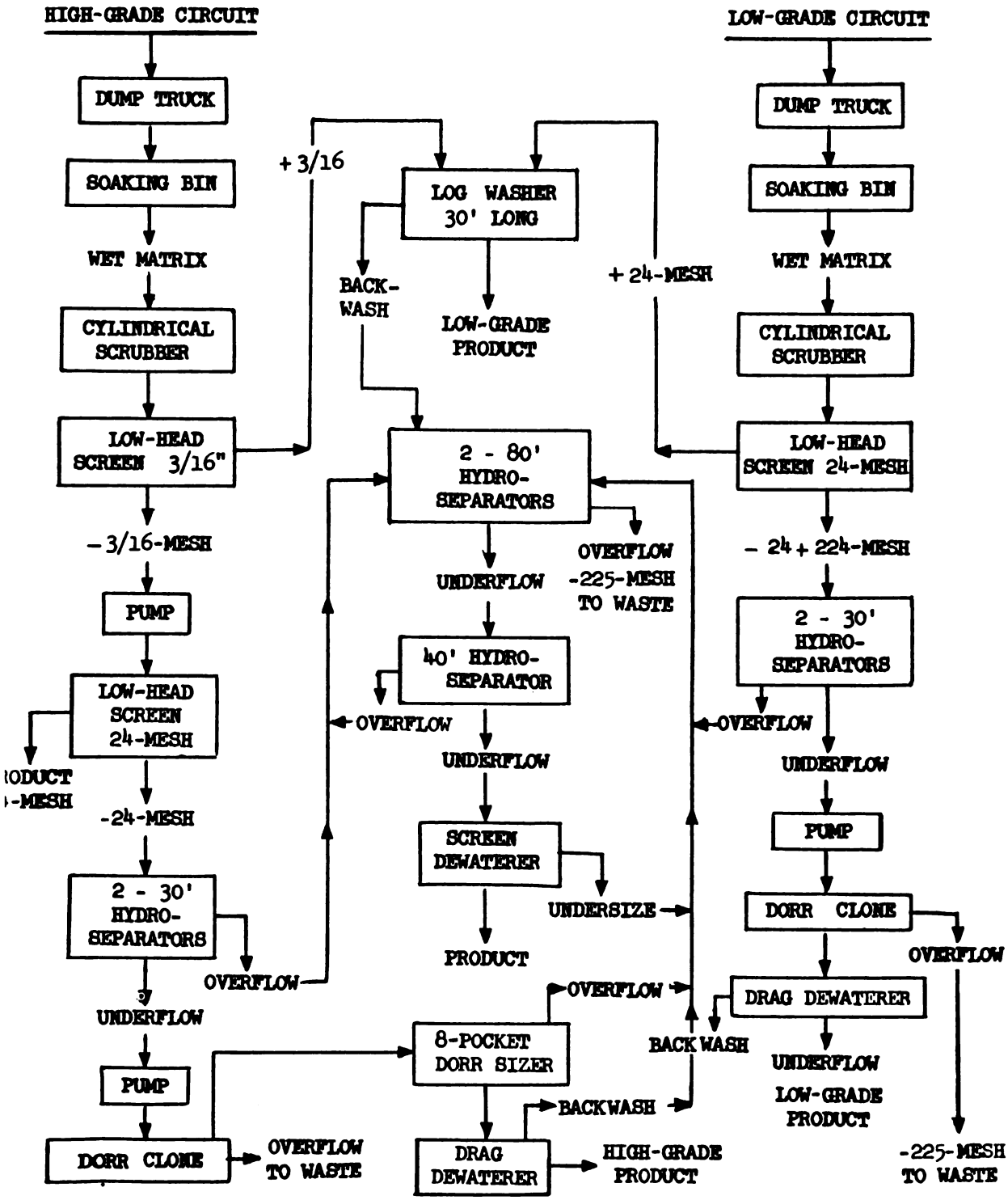

Figure 7. - Flowsheet of plant for washing Tennessee brown-rock phosphate.

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values and impose a disposal problem that is becoming progressively more serious (38). Huge areas must be provided for settling these slimes and for returning the water in which they are suspended to the washer plants for reuse. Even after settling for 2 or more years these slimes contain 75 percent of water, and no economic method of utilizing them has yet proved economically feasible. Limited studies have been made of the composition of these slimes, the nature and distribution of the contained phosphate minerals, and methods of treating the slime suspensions to effect selective flocculation of the phosphate minerals. So far, no great progress has been reported in upgrading this material to a point where it can be utilized as a source of P_2O_5.

Upward-current classifiers are used to remove the final traces of slime and separate the granular material into several sizes. The coarser fraction (approximately plus-28-mesh), in the form of a thickened pulp, is conditioned with anionic flotation reagents (consisting of a mixture of fatty acid, kerosine, fuel oil, and caustic soda) and treated on concentrating tables, spray belts, or in Humphreys spirals to separate the phosphate from the silica sand. The finer fractions (minus-28-, plus-200-mesh), after conditioning with anionic reagents, are fed to banks of flotation cells which yield a rougher concentrate. The rougher concentrate is then treated with dilute sulfuric acid, washed with water, conditioned with cationic flotation reagents, and passed through another bank of flotation cells where the silica is discarded as a froth and the phosphate settled out as a finished product.

The bulk of the phosphate rock is now recovered from the Florida-pebble deposits in the form of flotation concentrate. A typical flowsheet of a flotation plant suitable for recovering phosphate fines is shown in figure 8.

DRYING PHOSPHATE ROCK

Virtually all phosphate rock recovered by washing, screening, and flotation is dried before it is marketed. Some of the rock from the bedded deposits of the Western States is dried before being shipped.

Phosphate rock is dried in direct-fired rotary kilns 25 to 100 feet in length and 6 to 10 feet in diameter. Oil, natural gas, or powdered coal is used as a fuel and usually introduced countercurrent to the rock feed. The kilns are unlined but are equipped with flights to lift the rock and shower it through the hot gases of combustion. The fuel consumption varies with the moisture content and size of the rock. In the Florida-pebble field, where the wet rock averages 8 to 15 percent moisture, 3 to 10 gallons of fuel oil per long ton of rock is required to dry the rock to 1 percent moisture. A drying plant includes such auxiliaries as a boiler for preheating the fuel oil, dust collectors, feedbins, and conveyors.

When phosphate rock is defluorinated or nodulized, the kilns are lined with firebrick to withstand the high temperatures attained. Fuel consumption under these conditions is much greater than in ordinary drying operations, ranging from 25 to 100 gallons per ton of product, depending on the temperature required.

PRODUCTION COSTS

Because of the wide difference in the nature and mode of occurrence of the rock in the several phosphate fields of the United States, as well as fluctuations in the proportion of marketable rock recovered from individual deposits in the same field, it is difficult to estimate average production costs.

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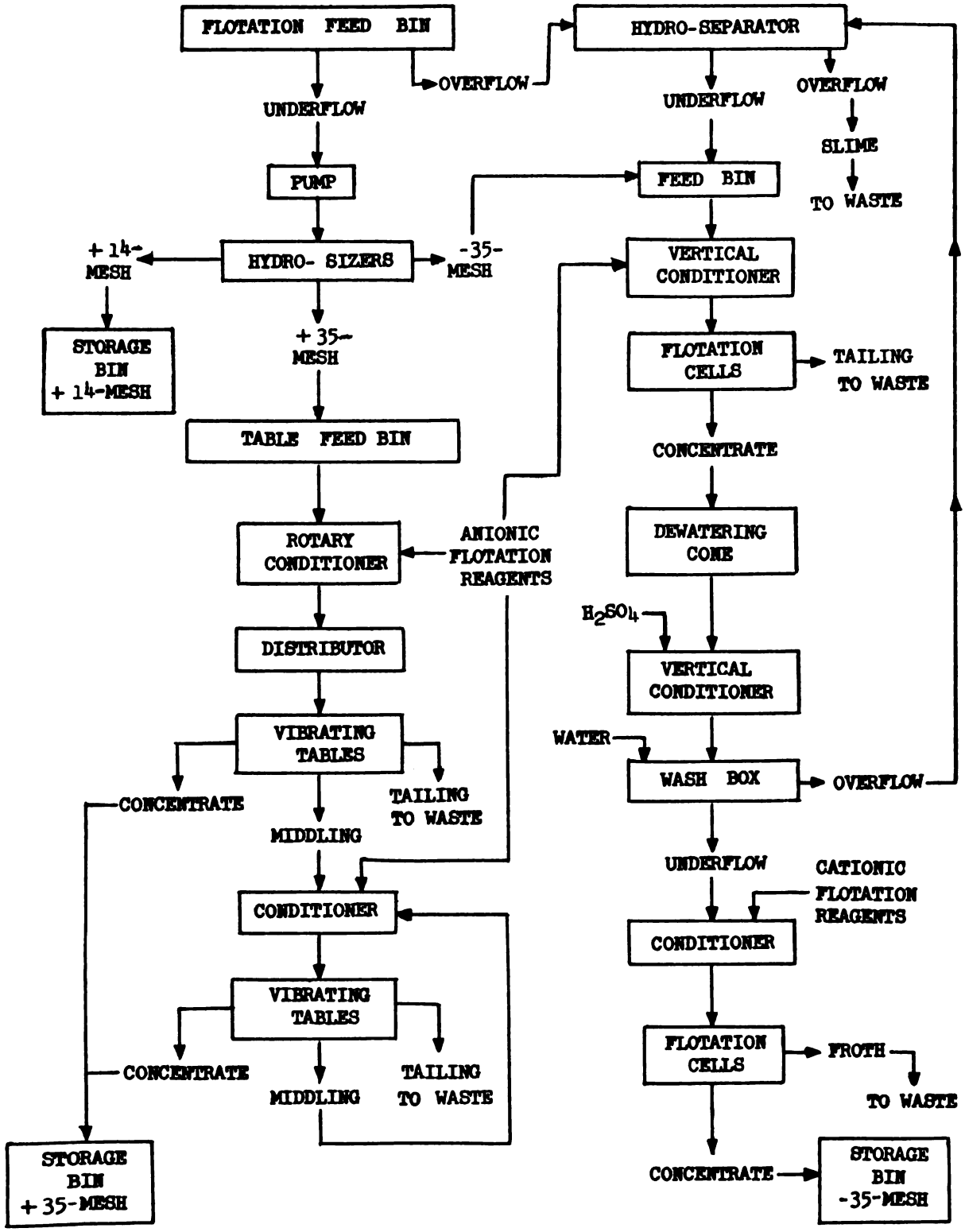

Figure 8. - Flowsheet of flotation plant for recovering fine sizes of Florida pebble phosphate.

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In certain localities relatively high mining costs may be permissible because the rock is of premium grade or the deposits are exceptionally well situated with respect to fuel, power, and other facilities required to convert the rock into concentrated finished products. In other localities lower mining costs may be more than offset by lack of such facilities.

Open-pit mining usually is less costly than underground mining, particularly where the phosphate beds are uniform in thickness over a large area and can be readily mined with a dragline or hydraulically.

In the Florida hard-rock and Tennessee brown-rock fields strip mining is more costly than in the Florida pebble field due to the irregular nature of the deposits and the lower overall recovery per acre. Florida hard-rock phosphate, however, is exceptionally high grade, and the Tennessee brown-rock deposits are particularly well located as regards electric furnaces producing elemental phosphorus in an area where low-cost power is available.

Strip mining is applicable to only a small proportion of the phosphate deposits in the western fields, but where practicable the cost is considerably lower than that of underground mining, particularly where both high-grade rock and marketable phosphatic shales can be recovered from the same deposit.

The average estimated cost of production per long ton of marketable phosphate rock from the various domestic fields is given in table 4, based on certain assumed conditions.

TABLE 4. - Average cost per long ton of producing marketable phosphate rock from domestic sources 1/

(Estimated by Bureau of Mines)

Items	Florida pebble	Florida hard rock	Tennessee brown rock	Western phosphates		
				High-grade rock	Low-grade phosphate shale	High-grade rock
	Strip mining	Strip mining	Strip mining	Strip mining	Strip mining	Underground mining
Overburden removal....	2/$0.30	2/$0.30	2/$0.40	2/$0.50	2/$0.50	-
Mining	3/1.20	3/4.00	3/3.75	4/3.25	5/1.25	4/$4.25
Washing					(6)	
Flotation	1.55	(7)	(7)	(7)	(7)	(7)
Drying and shipping ..	.45	.45	.45	8/.75	8/.75	8/.75
Depreciation	1.00	1.00	1.00	.50	.50	.50
General expenses 9/ ...	.50	.50	.50	.50	.50	.50
Total	5.00	6.25	5.70	5.50	3.50	6.00

1/ Exclusive of property cost or royalties.
2/ Assuming an average overburden of 24 feet.
3/ Assuming average thickness of matrix at 12 feet.
4/ Assuming average thickness of bed at 4 feet.
5/ Assuming average thickness of bed at 12 feet.
6/ No washing ordinarily required.
7/ No flotation employed.
8/ No drying but shipping costs higher than in Tennessee and Florida.
9/ General expenses include taxes and overhead.

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DOMESTIC INDUSTRY

The United States, the largest producer, supplies over 40 percent of the world output. The bulk of this production is consumed domestically, but a substantial tonnage is exported to European and Asiatic countries, as well as to Canada, Mexico, and South America. Salient statistics of the phosphate industry in the United States for 1954 and 1955 are listed in table 5.

The annual marketed output, exports, imports, and apparent consumption for 1900-55 are shown in figure 9. By far the greatest proportion of this tonnage is derived from the Florida land-pebble field. The next largest phosphate-producing State is Tennessee, followed by Idaho, Montana, Wyoming, and Utah, in the order named.

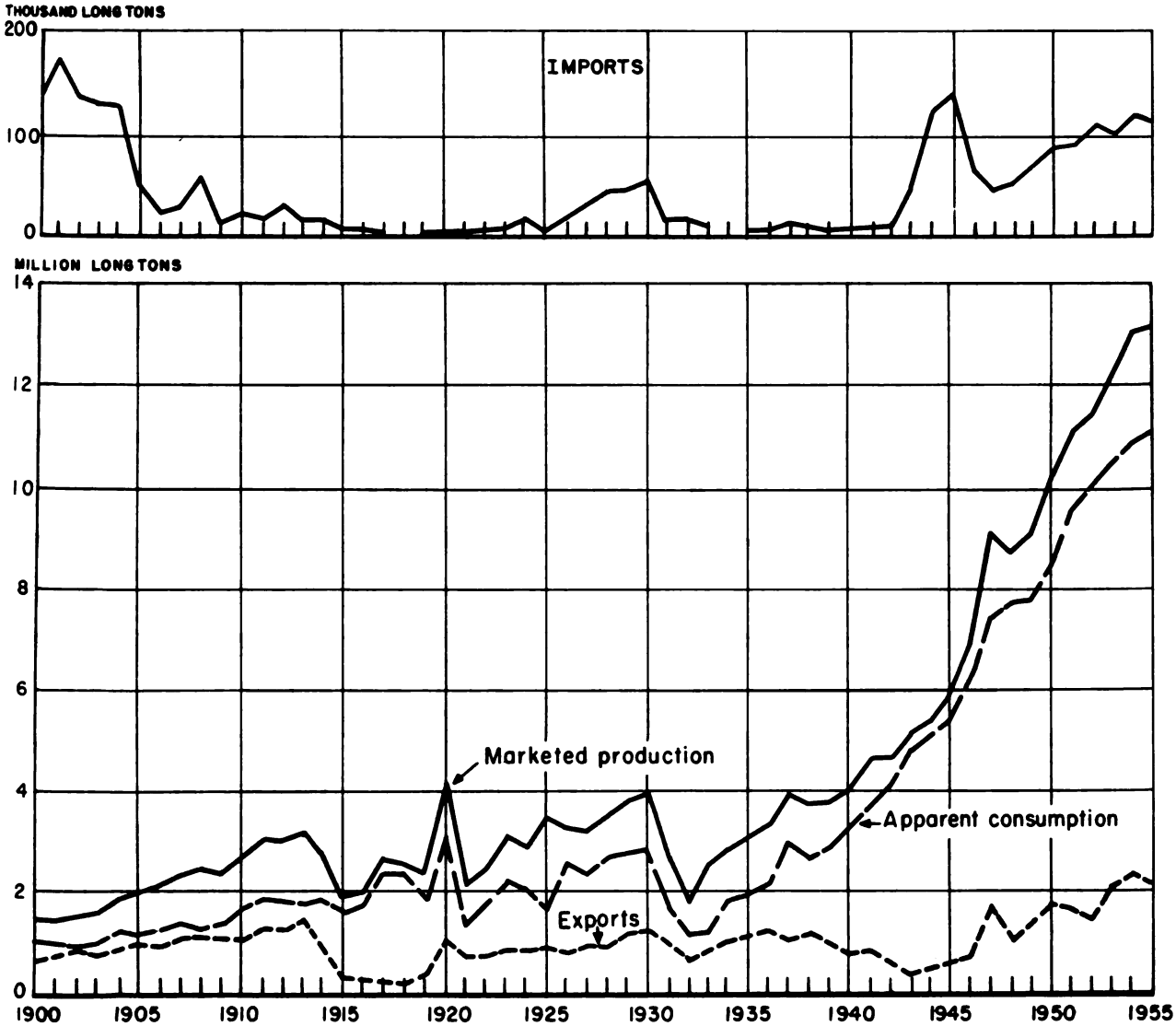

Figure 9. - Imports, marketed production, apparent consumption, and exports of phosphate rock in the United States, 1900-55.

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TABLE 5. - Salient statistics of the phosphate-rock industry in the United States, 1954-55

	1954				1955			
	Long tons		Value at mines		Long tons		Value at mines	
	Rock	P_2O_5 content	Total	Average	Rock	P_2O_5 content	Total	Average
Mine production	45,585,837	5,745,425	(1)	(1)	39,670,598	4,983,735	(1)	(1)
Marketable production 2/	13,821,100	4,359,955	3/$86,669,081	3/$6.27	12,265,248	3,886,732	3/$75,388,266	3/$6.15
Sold or used by producers:								
Florida:								
Land pebble	9,565,529	3,189,941	58,890,565	6.16	9,401,168	3,148,810	57,973,651	6.17
Soft rock	90,519	18,835	554,234	6.12	72,070	14,861	466,168	6.47
Hard rock	74,303	26,184	585,363	7.88	91,907	32,386	739,289	8.04
Total Florida	9,730,351	3,234,960	60,030,162	6.17	9,565,145	3,196,057	59,179,108	6.19
Tennessee	1,700,572	437,675	12,012,314	7.06	1,699,395	447,716	12,579,056	7.40
Western States:								
Idaho	878,920	231,833	4,299,824	4.89	1,122,012	297,122	5,550,745	4.95
Montana and Wyoming 4/	733,981	218,846	5,167,756	7.04	799,482	238,637	5,595,075	7.00
Total Western States	1,612,901	450,679	9,467,580	5.87	1,921,494	535,759	11,145,820	5.80
Total United States.	13,043,824	4,123,314	81,510,056	6.25	13,186,034	4,179,532	82,903,984	6.29
Imports	122,016	(1)	5/3,081,430	5/25.25	117,256	(1)	5/2,702,955	5/23.05
Exports 6/	2,278,572	752,011	14,971,010	6.57	2,183,084	719,695	14,269,300	6.54
Apparent consumption 7/	10,887,268	(1)	-	-	11,120,206	-	-	-
Stocks in producers' hands Dec. 31 6/:								
Florida	2,309,000	754,000	(1)	(1)	1,491,000	492,000	(1)	(1)
Tennessee 8/	463,000	124,000	(1)	(1)	229,000	65,000	(1)	(1)
Western States	9/596,000	9/160,000	(1)	(1)	10/1,085,000	10/274,000	(1)	(1)
Total stocks	9/3,368,000	9/1,038,000	(1)	(1)	10/2,805,000	10/831,000	(1)	(1)

1/ Data not available.
2/ See table 2 for kind of material produced.
3/ Derived from reported value of "sold or used."
4/ Includes a quantity from Utah.
5/ Market value (price) at port of shipment and time of exportation to the United States.
6/ As reported to the Bureau of Mines by domestic producers.
7/ Quantity sold or used by producers plus imports minus exports.
8/ Includes a quantity of washer-grade (matrix).
9/ Revised figure.
10/ Tonnage reflects midyear stock adjustments and stocks reported in midyear by producers that did not report production to the Bureau of Mines before July 1, 1955.

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The production of exceptionally high quality hard rock and soft phosphate in Florida represents a very small proportion (about 1.5 percent) of the total domestic output.

A partial list of phosphate-rock producers in the United States in 1956 is given in table 6.

The grades of phosphate rock marketed range from less than 20 percent to over 35 percent P_2O_5. Some of the lower grades are used directly or blended with higher grade phosphates in making up suitable charges for electric furnaces producing elemental phosphorus. The bulk of the higher grade rock (30 percent P_2O_5 or more) is treated with sulfuric acid or phosphoric acid to produce ordinary and concentrated superphosphate for fertilizer purposes.

Most companies that mine phosphate rock on a large scale also manufacture fertilizers and/or other phosphate products. Such companies consume all or a substantial portion of their output of phosphate rock.

The phosphate rock sold or used by producers in the United States in 1954-55, by grades and States, is given in table 7.

The figures in table 7 show that only 11 percent of the phosphate rock marketed in 1955 was of the highest grade (77 percent B. P. L.); 42 percent ranged in grade from 72 to 75 percent B. P. L.; 30 percent contained 60 to 66 percent B. P. L.; and 17 percent was low-grade rock containing less than 60 percent B. P. L. The bulk of the lower grade rock was mined in Tennessee and the Western States for the manufacture of elemental phosphorus.

Prices

Florida land-pebble phosphate rock is sold by the long ton. All other phosphate rock produced from domestic sources is sold by the short ton. Prices are based on the percentage of tricalcium phosphate, $Ca_3(PO_4)_2$(B. P. L.), present, and maximum allowable iron and aluminum oxides are usually specified. Bonuses are paid and penalties assessed for rock that is above or below the base grade.

Prices for relatively low grade rock (60 percent B. P. L. and lower) are not quoted on the open market, since they may vary considerably, depending on such factors as the distance of the deposits from plants equipped to use the material and whether or not the low-grade rock is in the nature of a byproduct obtained in producing higher grade rock. As pointed out previously, these low-grade phosphates often can be employed directly or blended with higher grade rock to obtain a suitable feed for electric furnaces producing elemental phosphorus.

The average values per ton at the mines of the phosphate rock marketed from various domestic sources in 1954 and 1955 are listed in table 5 (p. 24).

The prices for Florida pebble phosphate quoted by the Oil, Paint and Drug Reporter in 1955 are shown in table 8. The average prices of Tennessee brown rock, obtained through the courtesy of the Industrial and Agricultural Development Commission of the State of Tennessee, are also listed in table 8. Quotations on Florida hard rock, Tennessee brown phosphate, and western rock of several grades are seldom published, since they are usually agreed upon through direct negotiation between buyer and seller.

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TABLE 6. - Phosphate-rock producers in the United States, 1955, and type of operations

Field and company	Mine			Beneficiation plant		Drying or sintering plant	Fertilizer or chemical plant
	Open pit	Underground	Location	Washing plant	Other		
Florida land pebble:							
American Agricultural Chemical Co., 50 Church St., New York, N. Y.	X	-	Pierce, Fla.	X	X	X	X
American Cyanamid Co., 30 Rockefeller Plaza, New York, N. Y.	X	-	Brewster, Fla.	X	X	X	X
Armour Fertilizer Works, Atlanta, Ga.	X	-	Bartow, Fla.	X	X	X	X
Coronet Division, Smith-Douglass Co., Norfolk, Va.	X	-	Plant City, Fla.	X	X	X	-
Davison Chemical Corp., Baltimore, Md.	X	-	Bartow, Fla.	X	X	X	X
International Minerals & Chemical Corp., 20 N. Wacker Drive, Chicago, Ill.	X	-	do.	X	X	X	X
Swift & Co., Chicago, Ill.	X	-	Fort Meade, Fla.	X	X	X	X
Virginia-Carolina Chem. Corp., Richmond, Va.	X	-	Nichols, Fla.	X	X	X	X
Florida hard rock:							
Kibler-Camp Phosphate Enterprise, Ocala, Fla.	X	-	Dunnellon, Fla.	X	-	X	-
Florida soft rock:							
Camp Phosphate Co., Dunnellon, Fla.	X	-	Dunnellon, Fla.	-	-	-	-
Kellogg Co., Hernando, Fla.	X	-	Hernando, Fla.	-	-	X	-
Loncala Phosphate Co., High Springs, Fla.	X	-	Fort White and Newberry, Fla.	-	-	X	-
Soil Builders, Inc., Dunnellon, Fla.	X	-	Hernando, Fla.	-	-	X	-
Sun Phosphate Co., Dunnellon, Fla.	X	-	Dunnellon, Fla.	-	-	X	-
Superior Phosphate Co., Dunnellon, Fla.	X	-	[illegible]	-	-	-	-
Tennessee brown rock:							
Armour Fertilizer Works, Atlanta, Ga.	X	-	Columbia, Tenn.	X	-	X	X
Boyle, M. C. Phosphate Co., 407 S. Dearborn St., Chicago, Ill.	X	-	Centerville, Tenn.	-	X	X	-
Hall & England,[1] Mount Pleasant, Tenn.	X	-	Mount Pleasant, Tenn.	-	-	-	-
Harsh Phosphate Co., Nashville, Tenn.	X	-	Nashville, Tenn.	-	-	X	-
Highland Mining Co., Centerville, Tenn.	X	-	Centerville, Tenn.	X	-	X	-
International Minerals & Chemical Corp., 20 N. Wacker Drive, Chicago, Ill.	X	-	Wales and Mount Pleasant, Tenn.	X	X	X	X
McClanahan, W. P., & Co.,[2] Hickman County, Tenn.	X	-	Hickman County, Tenn.	-	-	-	-
Mine Equipment Co., Columbia, Tenn.	X	-	Columbia, Tenn.	-	-	-	-
Monsanto Chemical Co., St. Louis, Mo.	X	-	do.	X	-	X	X
Owens Agricultural Phosphate Co., Centerville, Tenn.	X	-	Centerville, Tenn.	-	-	X	-
Perry County Phosphate Co.,[3] Linden, Tenn.	X	-	Linden, Tenn.	-	X	-	-
Prince, J. T., Pulaski, Tenn.	X	-	Pulaski, Tenn.	-	-	-	-
Tennessee Valley Authority, Wilson Dam, Ala.	X	-	Columbia, Tenn.	-	-	X	X
Victor Chemical Works, 141 W. Jackson Blvd., Chicago, Ill.	X	-	Mount Pleasant, Tenn.	X	X	X	X
Virginia-Carolina Chem. Corp., Richmond, Va.	X	-	do.	X	X	X	X
Western rock:							
Anaconda Copper Mining Co., Anaconda, Mont.	X	X	Conda, Idaho	X	-	X	X
Monsanto Chemical Co., St. Louis, Mo.	X	-	Soda Springs, Idaho	-	-	X	X
Montana Phosphate Products Co., Garrison, Mont.	-	X	Garrison, Mont.	-	-	-	-
George Relyea, Garrison, Mont.	-	X	do.	-	-	-	-
San Francisco Chemical Co., Montpelier, Idaho	(X (X (-	X - X	Montpelier, Idaho Leefe, Wyo. Woodruff, Utah	))-)	X	-	-
J. R. Simplot Co., Pocatello, Idaho	(X (X	- -	Fort Hall, Idaho Randolph, Utah	- -	- -	- -	- X
Victor Chemical Works, Chicago, Ill.	-	X	Melrose, Mont.	-	-	X	X
Westvaco Chemical Division, Food Machinery & Chemical Co., Pocatello, Idaho	X	-	Caribou County, Idaho	-	-	X	X

1/ Brown and blue rock. 2/ Blue rock. 3/ White rock.

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TABLE 7. - Phosphate rock sold or used by producers in the United States in 1954-55, by grades and States

Grades-B. P. L.[1] content (percent)	Florida		Tennessee		Western States		Total United States	
	Long tons	Percent of total	Long tons	Percent of total	Long tons	Percent of total	Long tons	Percent of total
1954								
Below 60	221,850	2	1,222,007	72	811,908	50	2,255,765	17
60 to 66	60,599	1	288,931	17	70,419	4	419,949	3
68 basis, 66 minimum	1,700,830	17	103,785	6	308,463	19	2,113,078	16
70 minimum	1,198,807	12	85,544	5	351,154	22	1,635,505	13
72 minimum	1,378,940	14	-	-	70,957	5	1,449,897	11
75 basis, 74 minimum	3,656,293	38	305	(2)	-	-	3,656,598	28
77 basis, 76 minimum	1,513,032	16	-	-	-	-	1,513,032	12
Total	9,730,351	100	1,700,572	100	1,612,901	100	13,043,824	100
1955								
Below 60	146,860	1	1,172,312	69	999,670	52	2,318,842	17
60 to 66	1,784,471	19	374,048	22	414,635	22	630,623	5
68 basis, 66 minimum			153,035	9			3,308,181	25
70 minimum	859,014	9			353,601	18		
72 minimum	1,658,896	17	-	-	153,252	8	1,812,148	14
75 basis, 74 minimum	3,716,211	39	(3)	(3)	336	(2)	3,716,547	28
77 basis, 76 minimum	[4] 1,399,693	15	-	-	-	-	[4] 1,399,693	11
Total	9,565,145	100	1,699,395	100	1,921,494	100	13,186,034	100

1/ Bone phosphate of lime, $Ca_3(PO_4)_2$.
2/ Less than 0.5 percent.
3/ Included with 70 minimum grade.
4/ Includes a small quantity of higher grade rock.

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TABLE 8. - Prices of Florida pebble phosphate and Tennessee brown-rock phosphate, f. o. b. mines, by grades (as of Oct. 1, 1956)

Grades	Florida land pebble 1/	Tennessee brown rock 2/
68/66	$4.99	$6.60
70/68	5.39	6.80
72/70	5.99	7.00
75/74	6.99	-
78/76	7.99	-

1/ Per long ton; obtained from Oil, Paint and Drug Reporter.
2/ Per short ton; average prices obtained from Industrial and Agricultural Development Commission of the State of Tennessee.

Exports

In the 10-year period just before World War I phosphate-rock exports from the United States averaged about 1 million tons a year and represented 40 to 50 percent of the total marketed production. During both World Wars and in the depression period exports were curtailed.

The United States still maintains a substantial export trade, but since 1925 the development of the extensive deposits of phosphate rock in North Africa and in the U. S. S. R. has created a highly competitive foreign market. Phosphate rock exported from the United States in 1954 reached an alltime high of 2,279,000 long tons, less than 18 percent of the total marketed production. Because of their favorable location with respect to the foreign market, it is expected that the phosphate deposits of North Africa and the U. S. S. R. will continue to supply the bulk of the phosphate requirements of Europe, as well as those of certain Asiatic countries.

The annual exports of phosphate rock from the United States during the period 1937-55 and their relation to the total quantities marketed are shown in figure 9.

Imports

The imports of crude phosphates into the United States represent a very small proportion of the total domestic consumption. During 1927-30 appreciable tonnages of phosphate rock were imported from North Africa, and in 1931 and 1932 several shipments of Russian apatite were received. From 1943 to 1945 imports of apatite and crude phosphate rock totaled more than 310,000 long tons, mainly from the U. S. S. R. and North Africa. Imports from North Africa and the U. S. S. R. ceased in 1945, and there have been no shipments to the United States since.

Since World War II the only crude phosphate rock imported into the continental United States has come from the Island of Curaçao (Netherland West Indies). These phosphates are exceptionally high grade and contain such a low percentage of fluorine that they can be used directly as an animal feed supplement. The annual imports of crude phosphates (unmanufactured) for 1900-55 are shown in figure 9. The quantity imported in 1955 was 117,000 tons, about 1 percent of the apparent domestic consumption.

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USES OF PHOSPHATE ROCK

Although a substantial quantity (825,000 long tons in 1955) of raw phosphate rock is finely ground and applied directly to the soil, the bulk of that produced is decomposed by heat and chemical treatments and converted into fertilizer and various types of finished products.

The main phosphate product is superphosphate, which constitutes the basic phosphate ingredient of nearly all commercial fertilizers. In recent years an increasing proportion of phosphate rock has been consumed in manufacturing phosphorus, phosphoric acid, and phosphate products for a wide variety of industrial purposes.

Elemental phosphorus is an important military material as a constituent of incendiary bombs and in laying down smoke screens to conceal troop concentrations and the movement of naval vessels. Substantial quantities of phosphorus are used in manufacturing phosphorus chloride and phosphorus oxychloride, which, in turn, are used to produce certain organic plasticizers, insecticides, and gasoline and lubricating-oil additives.

Large tonnages of phosphoric acid derived from elemental phosphorus, as well as from the reaction of phosphate rock with sulfuric acid, are used in the manufacture of detergents, water-softening compounds for boilers, and leavening agents; substantial tonnages of this acid also are employed in rustproofing metals and in fireproofing textiles; smaller quantities of various phosphate compounds are used in sugar refining, in catalysts, in special cements, as a mild abrasive, and in photographic processes.

Table 9 gives the quantities of phosphate rock sold or used for agricultural purposes, as well as for the manufacture of elemental phosphorus, phosphoric acid, and other industrial products.

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TABLE 9. - Phosphate rock sold or used by producers in the United States, 1954-55, by uses and States

Uses	Florida		Tennessee		Western States		Total United States	
	Long tons		Long tons		Long tons		Long tons	
	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content	Rock	P_2O_5 content
1954								
Domestic:								
Agricultural:								
Ordinary superphosphate	4,912,435	1,668,767	77,113	24,297	79,628	25,457	5,069,176	1,718,521
Triple superphosphate	1,036,406	337,293	40,832	11,392	1/220,481	1/68,922	1,297,719	417,607
Nitraphosphate	12,851	4,403	-	-	-	-	12,851	4,403
Direct application to soil	543,003	165,922	166,829	49,700	64,184	20,539	774,016	236,161
Stock and poultry feed	124,747	39,074	18,617	5,585	893	286	144,257	44,945
Fertilizer filler	-	-	13,764	2,975	-	-	13,764	2,975
Other2/	-	-	45,942	12,648	-	-	45,942	12,648
Total agricultural	6,629,442	2,215,459	363,097	106,597	365,186	115,204	7,357,725	2,437,260
Industrial:								
Elemental phosphorus, ferrophosphorus, phosphoric acid	696,866	224,505	1,333,158	329,888	934,130	236,671	2,964,154	791,064
Phosphoric acid (wet process)	439,056	141,789	-	-	(1)	(1)	439,056	141,789
Other3/	-	-	4,317	1,190	-	-	4,317	1,190
Total industrial	1,135,922	366,294	1,337,475	331,078	934,130	236,671	3,407,527	934,043
Exports4/	1,964,987	653,207	-	-	313,585	98,804	2,278,572	752,011
Grand total	9,730,351	3,234,960	1,700,572	437,675	1,612,901	450,679	13,043,824	4,123,314
1955								
Domestic:								
Agricultural:								
Ordinary superphosphate	4,618,100	1,587,070	5/209,628	5/58,557	126,097	39,696	4,953,825	1,685,323
Triple superphosphate	1/1,598,910	1/517,980	(5)	(5)	1/378,183	1/119,140	1,977,093	637,120
Nitraphosphate	(6)	(6)	-	-	-	-	(6)	(6)
Direct application to soil	661,702	203,886	144,076	42,951	19,769	6,324	825,547	253,161
Stock and poultry feed	189,309	56,685	21,028	4,960	1,071	342	211,408	61,987
Fertilizer filler					-	-		
Other2/	11,556	3,900	99,000	25,000	-	-	110,556	28,900
Total agricultural	7,079,577	2,369,521	473,732	131,468	525,120	165,502	8,078,429	2,666,491
Industrial:								
Elemental phosphorus, ferrophosphorus, phosphoric acid	604,911	202,156	1,220,473	314,730	1,092,447	274,492	2,917,831	791,378
Phosphoric acid (wet process)	(1)	(1)	-	-	(1)	(1)	(1)	(1)
Other3/	1,500	450	5,190	1,518	-	-	6,690	1,968
Total industrial	606,411	202,606	1,225,663	316,248	1,092,447	274,492	2,924,521	793,346
Exports4/	1,879,157	623,930	-	-	303,927	95,765	2,183,084	719,695
Grand total	9,565,145	3,196,057	1,699,395	447,716	1,921,494	535,759	13,186,034	4,179,532

1/ Rock for phosphoric acid (wet process) included with triple superphosphate.
2/ Includes phosphate rock used in calcium metaphosphate, fused tricalcium phosphate, nitraphosphate, and other applications.
3/ Includes phosphate rock used in pig-iron blast furnaces, parting compounds, research, defluorinated phosphate rock, refractories, and other applications.
4/ As reported to the Bureau of Mines by domestic producers.
5/ Rock for triple superphosphate included with ordinary superphosphate.
6/ Included with "Other" agricultural.

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